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Extensive Studies of Fertilizing and Thinning Coastal Douglas-fir and Western Hemlock: An Establishment Report

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Extensive Studies of Fertilizing and Thinning Coastal Douglas-fir and Western Hemlock: An Estabishment Report

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ABSTRACT

Nine hundred and forty permanent 0.05- to 0.10-ha plots were established in the Vancouver Forest Region by the B.C. Forest Productivity Committee in 1971-1975 to study the effects of thinning and/or fertilizing pure and mixed stands of immature Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.). The core study examined the effects of various levels and combinations of thinning (0, 20, 35% live basal area removed) and nitrogen fertilization (0, 225, 450 kg N/ha) on tree growth. Subsidiary studies examined operational thinning or fertilization, and effects of thinning and fertilizing in juvenile stands. Tree diameters and heights were measured and pathological characteristics evaluated before and after treatment, and at 3-year intervals since establishment. Vegetation and soils were described for each installation, and weather stations were maintained at or near each installation for up to 8 years. This report, a collation of published and unpublished information, provides a summary of the methods of plot establishment and measurement.

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FOREWORD

This establishment report, prepared 13 years after study establishment was completed, is a collation of information from a variety of sources including:

- a draft establishment report prepared by P. R. Barker before leaving Research Branch; B.C. Ministry of Forests, Victoria;
- an assortment of correspondence and internal memoranda, file notes, early field data sheets, survey summaries, access notes, and plot descriptions filed at the Research Branch;
- the project working plan and three revisions produced before and during plot establishment;
- the B.C. Ministry of Forests' Field Operations Manual and three revisions produced since the time of project establishment, for managed growth and yield stands;
- a portion of a chapter (and its update) in the B.C. Ministry of Forests' Forest and Range Inventory Manual concerning remeasurement of managed growth and yield stands; and
- interviews with individuals involved in the core project and auxiliary studies from early in the program.

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1 Establishment dates, measurement dates, and stand characteristics of standard installations (Nos. 1–72), industrial installations (Nos. 73–79), and installations established in stands less than 15 years old (Nos. 80–85) 20

1 INTRODUCTION

British Columbia's Forest Productivity Committee (FPC) was established by the Deputy Minister of Forests in 1970 to study timber yields in intensively managed stands. From 1971 to 1975, the Committee set up an extensive field program to investigate the effects of fertilizing and thinning immature stands of coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.). This was based on recommendations made by G.C. Warrack.[1,2]

The FPC field program, also referred to as Research Branch's Experimental Project (EP) 703, focussed on forests within the coastal Inventory Zones 1 and 2 (B.C. Department of Lands and Forests 1957) which fall within the boundaries of the present-day Vancouver Forest Region (Figure 1). These zones are among the most productive in the province, are often easily accessible, and are located close to major markets. The study consists of 85 installations containing 940 0.05- to 0.10-ha permanent plots. These are established at numerous locations in stands of various ages (10–79 years), site indices (16–38 m at 50 years total age), soil types, and environmental conditions. The study plots represent various treatments, consisting of combinations of several levels of thinning and nitrogen fertilization. A large data base has been accumulated as a result of six remeasurements at 3-year intervals (including before treatment). Further remeasurements after 1987 will be based on a 6-year interval.

This report, which summarizes the EP 703 study objectives and methodology (design, establishment, treatments, and measurements), is to be used as a reference in subsequent papers reporting growth responses and other results of the study.[3] It also outlines ancillary studies associated with the FPC study.

2 STUDY OBJECTIVES

The goal of the FPC study was to create an extensive and comprehensive data base from which to direct future intensive forest management practices in coastal British Columbia. The objectives of the study were:

1. to examine basal area and volume growth response of immature Douglas-fir and western hemlock to thinning and/or fertilizer application under a variety of stand, edaphic, and climatic conditions;
2. to construct growth and yield tables for fertilized and thinned stands of immature Douglas-fir and western hemlock; and
3. to determine levels of fertilization and/or thinning that provide optimal yield from immature Douglas-fir and western hemlock.

3 METHODS

The FPC program consists of three types of installations (Table 1): 1) 72 "standard" installations (806 plots) which received carefully applied treatments and make up the core of the project; 2) 7 "industrial" installations (98 plots) which received operationally applied thinning or fertilizer treatments; and 3) 6 "juvenile" installations (36 plots) which were established to study fertilization and thinning in stands less than 15 years old. The design, establishment, treatment, and measurement of each installation type is described below.

---

1 G.C. Warrack. 1970. Improved forest productivity for British Columbia: a problem analysis of research needs in growth and yield. B.C. For. Serv., Dep. Lands For. Water Resources. (Available from B.C. Min. For., Res. Branch, Victoria, B.C.). Unpubl. rep.

2 G.C. Warrack. 1970. Productivity of intensively managed forests: program notes and resolutions. B.C. For. Serv., Dep. Lands For. Water Resources. (Available from B.C. Min. For., Res. Branch, Victoria, B.C.). Unpubl. rep.

3 A comprehensive file report has been prepared (L.M. Darling and S.A.Y. Omule. 1988. Extensive studies of fertilizing and thinning coastal Douglas-fir and western hemlock: an establishment report. B.C. Min. For., Res. Branch, File EP 703, Victoria, B.C.). It provides further details of methods and rationale of all aspects of project design, establishment, treatments, measurement, and ancillary studies.

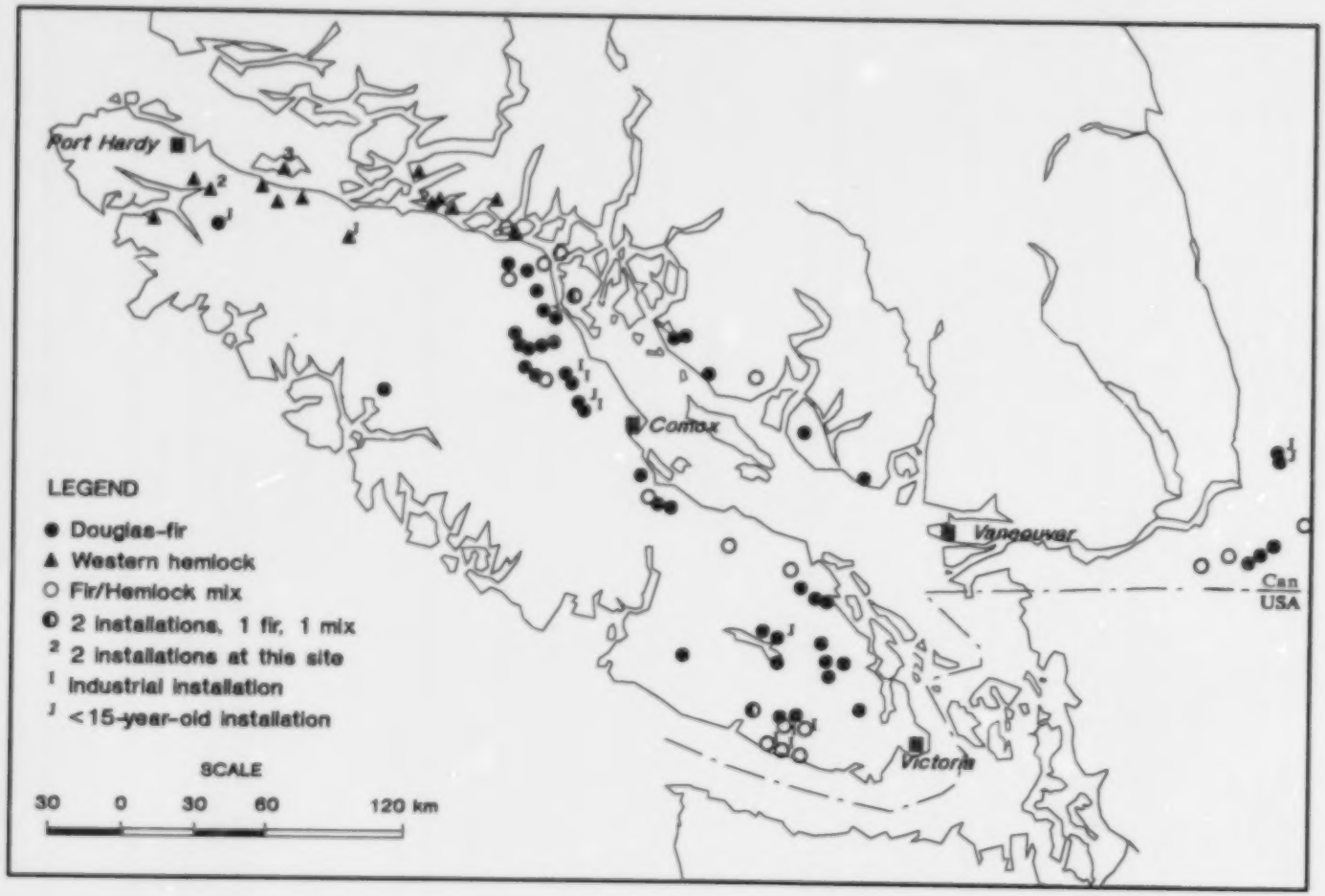


FIGURE 1. Study area map showing location and stand type of 85 installations in EP 703.

TABLE 1. Number of plots and installations established for EP 703, summarized by installation type and stand type[a]

Installation type	No. installations					No. plots				
	pure Fd	Fd-dom. mix	pure Hw	Hw-dom. mix	Total	pure Fd	Fd-dom. mix	pure Hw	Hw-dom. mix	Total
Standard	37	15	17	3	72	370	154	232	50	806
Industrial	3	1	0	3	7	72	10	0	16	98
Juvenile	5	0	1	0	6	30	0	6	0	36
Total	45	16	18	6	85	472	164	238	66	940

[a] Stand type determined by percent species composition by basal area:
pure — more than 80% one particular species, perhaps with a minor (10–20%) contribution of other species.
species-dominated mix — a mixed stand dominated (50–80%) by one species, with minor (10–20%) or major (>20%) contribution by other species.
Fd: Douglas-fir; Hw: western hemlock.

3.1 Standard Installations[4]

3.1.1 Experimental design

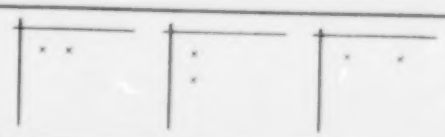
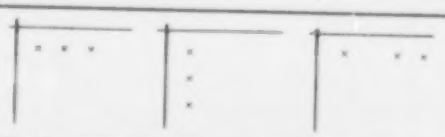
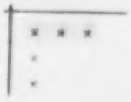
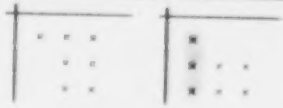
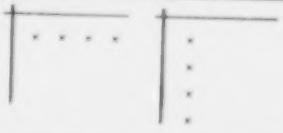
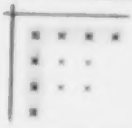
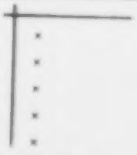
The study was planned as a randomized complete block design. It was intended to test three levels of thinning (0, 20, and 35% of live basal area removed) and three levels of fertilizing (0, 225, and 450 kg N/ha) in a complete 3 × 3 factorial arrangement, replicated twice over the nine treatment combinations in each installation. The design was altered as establishment of the study progressed because it was difficult to find uniform, single-species sites of sufficient size to accommodate 18 plots. In addition, the thinning and fertilizing treatments were expanded to include higher levels of thinning (50%) and fertilizing (675 and 900 kg N/ha). Some installations, therefore, had more than 18 plots, others had less. The resultant breakdown of experimental designs actually applied is complex (Table 2). For example, of the 72 standard installations, only 8 conform to the replicated 3 × 3 factorial, 18-plot layout; and 16 installations do not have control plots. Methods of thinning and fertilizer application were consistent among all experimental designs.

Plots were square, and plot size (0.05, 0.07, or 0.10 ha) was selected to meet the requirement of at least 60 live trees per plot before thinning. If a stand had over 1200 stems per hectare, plot size was 0.05 ha. Plot size was larger in older stands where stocking was less dense: 0.07 ha for 860–1200 stems per hectare, and 0.10 ha for 600–860 stems per hectare (Table 3; Appendix 1). Plot size was identical within an installation but varied among installations according to stocking levels.

Each plot was surrounded by a buffer that was equal in area to the plot size and had approximately the same stand characteristics as the plot. Outer edges of buffers were at least 12 m from adjacent plot buffers and major topographic or stand discontinuities (Figure 2).

Plots within an installation were ranked by preliminary basal area of plot plus buffer, and assigned to two equal-sized blocks described as "large basal area" and "small basal area." A treatment was then randomly assigned to one plot from each of the two blocks, thereby providing replicate pairs of treatments. Treatments were applied to plots and associated buffers.

[4] Details and revisions of field methods for establishment and measurement of standard installations are found in B.C. Dep. Lands. For. Water Resources, 1972, 1973, 1975; and B.C. Min. For. 1977, 1981, 1985.

Design code	Installations this design	Design description	Design layout examples[a]
1	41,42,49,53, 54,55,57,62, 63,66,67,68	1 x 2	
2	19,20,31,32, 34,48,51,52, 61,65	1 x 3	
3	7,10,13,14, 16,43,64	2 - 1 x 3 from 'broken' RCB design	
4	8,22,25,44, 46	1 x 3 sheared off other treatment combinations 2 x 3, control related to only one factor	
5	11,12,18,60, 70	1 x 4	
6	33,35,38	2 - 1 x 4 sheared off other treatment combinations - includes full 3 x 3 also	
7	29,69	1 x 5	

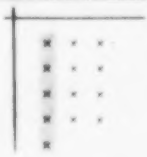
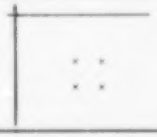
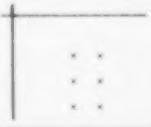
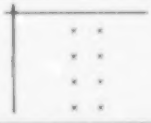
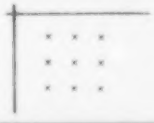
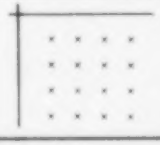
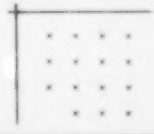
[a] Simplified layout diagrams illustrate treatment combinations applied to two replicate plots within an installation. In this example, there are plots on the installation: 2 were control plots, 2 received the 20% thinning treatment, 2 received 450 kgN/ha, and 2 received 20% thinning plus 450 kgN/ha.

	Thinning 0	1	2
Fertilizing 0	·		·
1			
2	·		·

Fertilizing codes: 0 control
1 225 kgN/ha applied
2 450 kg
3 675 kg
4 900 kg

Thinning codes: 0 control
1 20% BA removed
2 35%
3 50%

TABLE 2. Experimental designs applied to standard installations

Design code	Installations this design	Design description	Design layout examples[a]
8	28	1 x 5 sheared off other treatment combinations - includes full 3 x 3 also	
9	6,9,15,17, 21,24,26,27 59	2 x 2, no control plots	
10	23,37,41, 58	2 x 3, no control plots	
11	36,45,50	2 x 4, no control plots	
12	1,2,3,4,5, 47,71,72	3 x 3 original factorial design	
13	30,56	complete 4 x 4, includes full 3 x 3	
14	40	incomplete 4 x 4, includes full 3 x 3	

[a] Simplified layout diagrams illustrate treatment combinations applied to two replicate plots within an installation. In this example, there are plots on the installation: 2 were control plots, 2 received the 20% thinning treatment, 2 received 450 kgN/ha, and 2 received 20% thinning plus 450 kgN/ha.

	Thinning 0	1	2
Fertilizing 0	·		·
1			
2	·		·

Fertilizing codes: 0 control; 1 225 kgN/ha applied; 2 450 kg; 3 675 kg; 4 900 kg

Thinning codes: 0 control; 1 20% BA removed; 2 35%; 3 50%

TABLE 2. ***Continued***

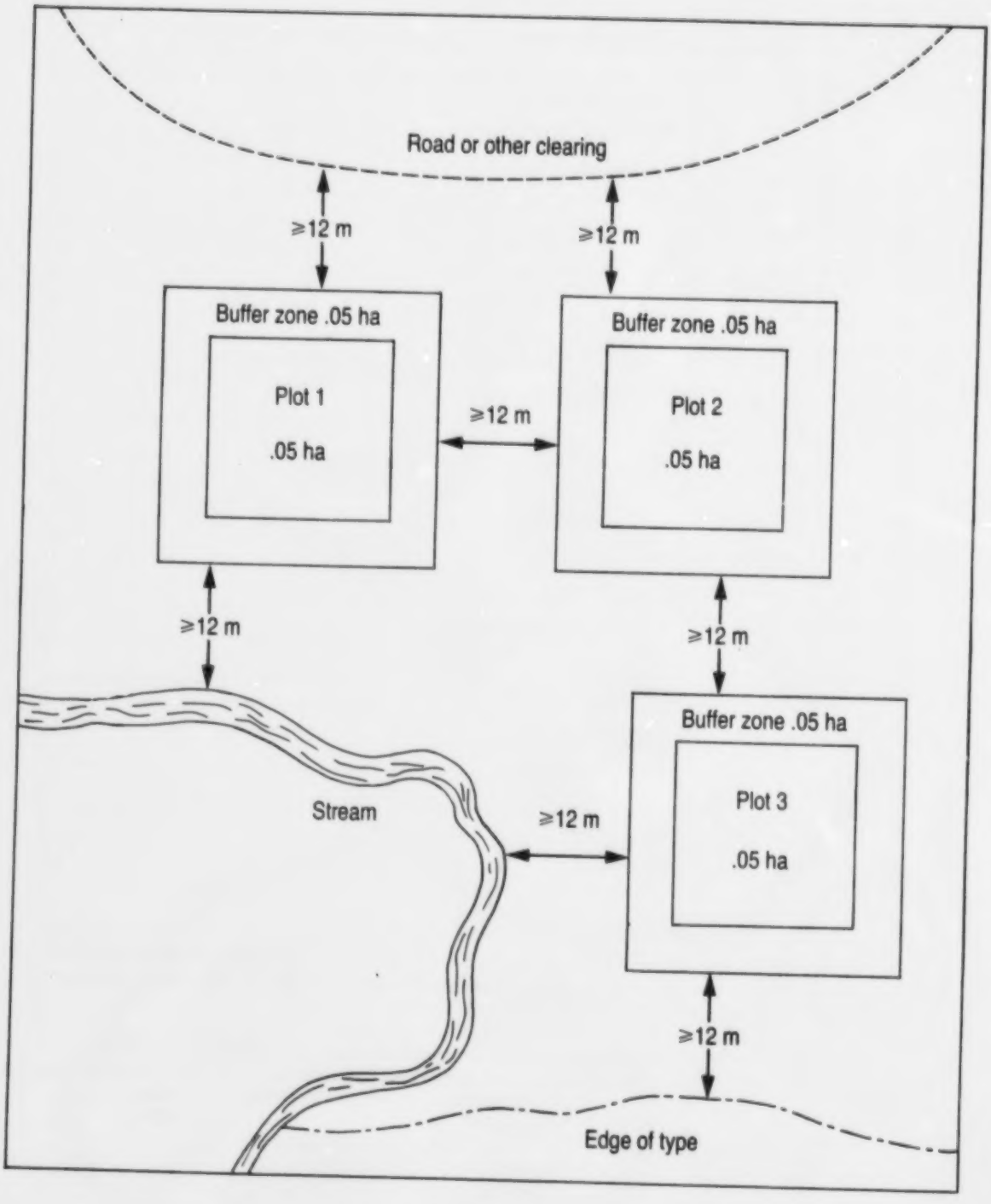


FIGURE 2. Plot layout illustrating specifications of buffer zones, isolation areas, and proximity to stand or topographic irregularities in standard installations. Source: B.C. Dep. Lands For. Water Resources (1972).

TABLE 3. Plot specifications for standard plots established for EP 703

Parameter	Plot size		
	.05 ha	.07 ha	.10 ha
Buffer zone area	.05 ha	.07 ha	.10 ha
Isolation area width	12+ m	12+ m	12+ m
Length of plot side	22.36 m	26.46 m	31.62 m
Length of buffer side	31.62 m	37.42 m	44.72 m
Buffer width	4.63 m	5.48 m	6.55 m
Minimum distance between plot centres	43.62 m	49.42 m	56.72 m
Number of living stems per plot	60+	60+	60+
Number of stems per hectare	1200+	860–1200	600–860

3.1.2 Evaluation of research sites

Preliminary assessment of potential sites, based on aerial photographs, forest cover maps, soil profiles, and stand and vegetation surveys, assured that the selected stands:

1. had at least 80% (by volume) of Douglas-fir and/or western hemlock aged 15 to 80 years;
2. were uniform in terms of stand height, age, stocking, canopy closure, and aspect;
3. were on flat terrain or even, unbroken slopes usually less than 40%;
4. were not extensively subdivided by streams, roads, trails, or patches of other species;
5. were free from extensive pathological agents (e.g., root rot, mistletoe) and mechanical damage;
6. were located on homogeneous geo-units (Keser 1970) and that soils belonged to a single Great Group (Day and Lajoie 1973); and
7. were large enough to accommodate at least four plots plus associated buffers.

3.1.3 Plot establishment

On selected sites, plots were laid out with a tape and staff compass. A 10 × 10 cm cedar post was installed at plot centre and aluminum tubes were placed at plot and buffer corners. In each plot, all living and dead trees with dbh greater than 5.0 cm were painted at breast height (1.3 m above germination point). A numbered plastic tag was attached to each tree, 8–10 cm above breast height, with an aluminum nail.

Fifty standard installations were established in stands that originated from natural regeneration following clearfelling of old growth between 1907 and 1945, and slashburning or wildfires from 1917 to 1951. Three installations include a mixture of naturally regenerated and planted trees. The remainder are located in plantations that were established with 1+0, 2+0, and 3+0 bareroot stock raised at Green Timbers, Quinsam, and Duncan nurseries with seed collected from a variety of sources (primarily Lower Mainland and Vancouver Island.) Details of site and stand history are available in Appendix 4 of the comprehensive establishment report.[5]

Root rot and pathogen surveys of all Forest Productivity Committee plots were conducted by Canadian Forest Service personnel (1) to identify centres of substantial infection when plots were being located, and (2) to locate individual trees with infections so that rate of spread could be determined later.

[5] Darling and Omule, 1988.

Surveys were completed in 1976. Fungal species specifically investigated were *Phellinus weirii*, *Fomes annosus*, and *Armillaria mellea*, but *Poria subacida* and *Poria rivulosa* were occasionally encountered. Data are on file at the Research Branch; no reports were prepared.

3.1.4 Preliminary plot measurement

Preliminary measurement and evaluation of trees in the plots (Table 4) took place during the summer shortly after plot establishment, but before thinning or fertilizer treatments. Tree class code (healthy, suspect, dead), crown class (dominant, co-dominant, intermediate, overtopped), lean or sweep, position of base of live crown, pathological condition (scars, frost cracks, dead top, etc.), and dbh at 1.3 m above germination point were recorded for each tree at least 5.0 cm dbh. Buffer trees were also measured for dbh. Preliminary standing basal area was calculated for each plot plus buffer, and treatments were assigned according to basal area (Section 3.1.1).

A sample of healthy, dominant and co-dominant trees of the predominant species on each plot was measured for total height and total age, to determine site index of each plot and installation. Total age was determined by boring the tree, preferably at 30 cm above the germination point, and using appropriate age correction tables (B.C. Ministry of Forests 1977). Selection of sample trees measured for height and age was determined as follows: 1) in pure stands at least 10 trees per plot were measured for height (most sample trees were co-dominants, although some dominants were also measured); 2) in stands with an approximately even mix of fir and hemlock at least 10 trees were measured for each species; and 3) at least 5 of the larger diameter trees per plot were measured for total age. Selection of height sample trees was altered over the course of the project (Section 3.1.6). Site index of each plot was determined from site index curves and tables (Hegyi *et al.* 1981).

A sample of plots was checked after the preliminary measurement for accuracy of tree measurements and plot dimensions. Subsequent dbh and height measurements were compared to previous values to ensure that they were within expected 3-year growth limits. (For details see Appendix 5B of the comprehensive establishment report.[6])

3.1.5 Thinning and fertilizer treatments

Sixty standard installations received fertilizer treatment. Nitrogen, in the form of prilled urea (46% nitrogen), was applied over selected plots and associated buffers by hand from a bucket or model 57 Cyclone seeder. To obtain uniform coverage, the plot was divided into four strips of equal area, and fertilizer was weighed separately for each; sides of the buffer were also treated individually. Fertilizer was distributed before thinning was conducted, and was usually applied in the dormant season.

Thinning was conducted in 55 standard installations. A modified crown thinning was done in the dormant season, based on the following criteria:

1. good quality dominant and co-dominant trees of the predominant species were favoured as residuals;
2. residual stems were distributed approximately uniformly throughout the plot and buffer;
3. a d/D ratio (mean diameter of live stems removed in thinning divided by mean stand diameter before thinning) was maintained at 0.80–0.90;
4. the total live basal area removed was kept within 5% of the prescribed thinning percent;
5. malformed, damaged, and diseased co-dominant and intermediate trees were removed;
6. broad-leaf species, wolf trees, and slender, wind-blown stems were removed whenever possible; and
7. all dead trees were removed.

Thinning levels of 20, 35, and 50% of live basal area corresponded to approximately 80, 65, and 50% canopy closure after thinning, respectively.

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[6] Ibid.

TABLE 4. Ranges of preliminary (pre-treatment) conditions[a] of Forest Productivity Committee installations. Details by installation are provided in Appendix 1

Parameter	Installation type		
	Standard	Juvenile	Industrial
No. of installations	72	6	7
Date of establishment	1971–1975	1975	1973–1975
No. plots per installation	4–32	4–8	4–43
Plot size (ha)	0.05,0.07,0.10	0.05	0.05
Installation stand type[b]			
pure Fd stands	37 installations (370 plots)[c]	5(30)	3(72)
Fd — dominated mix	15 installations (154 plots)	—	1(10)
pure Hw stands	17 installations (232 plots)	1(6)	—
Hw — dominated mix	3 installations (50 plots)	—	3(16)
Mean site index (m at 50 years):			
all installations	16–38		21–28
pure Fd stands	16–38		21–25
Fd-dominated mix	16–32	N/A	28
pure Hw stands	25–35		—
Hw — dominated mix	19–31		23–28
Mean total age (years):			
all installations	16–80	12–16	16–39
pure Fd stands	16–72	12–16	16–39
Fd — dominated mix	26–80	—	29
pure Hw stands	31–64	13	—
Hw — dominated mix	30–53	—	27–32
Mean stand density (stems/ha):			
all installations	717–6378		1458–4910
pure Fd stands	717–3534		1458–1726
Fd — dominated mix	822–4310	N/A[d]	2874
pure Hw stands	787–6378		—
Hw — dominated mix	1211–4987		2635–4910
Mean basal area (m^2/ha):			
all installations	19–84		24–58
pure Fd stands	22–73		24–32
Fd — dominated mix	19–80	N/A	53
pure Hw stands	57–84		—
Hw — dominated mix	43–81		43–58
Mean height (m):			
all installations	10–41	3–7	6–21
pure Fd stands	10–40	3–7	6–21
Fd — dominated mix	12–36	—	18
pure Hw stands	16–41	5	—
Hw — dominated mix	12–32	—	15–16
Quadratic mean dbh (cm):			
all installations	9.7–36.6		12.2–16.7
pure Fd stands	10.1–30.5		14.6–16.7
Fd — dominated mix	9.9–35.4	N/A	15.4
pure Hw stands	9.7–36.6		—
Hw — dominated mix	10.5–29.0		12.2–14.3

[a] No preliminary measurements were taken for industrial or juvenile stands because results did not help to assign treatments. However, in industrial installations, initial (post-treatment) measurements were entered as preliminary measurements, and in juvenile installations sub-plot sampling determined pre-treatment density and species composition (see Sections 3.2.2 and 3.3.2).

[b] Stand type: pure stands have more than 80% basal area in one species; species-dominated stands have 50–80% basal area in that species; Fd = Douglas-fir, Hw = western hemlock.

[c] Number of plots represented by installations that are defined as a particular stand type. Actual stand type on individual plots may vary from stand type described for whole installation.

[d] Often very much greater than 2500 stems per hectare before treatment.

Felling was conducted soon after fertilizing and each stump was treated with a solution of 20% sodium tetraborate (borax) or 10% zinc chloride to prevent fungal infection. Thinnings from various installations — 257 Douglas-fir and 137 western hemlock trees — were used to develop tree volume equations for small Douglas-fir and western hemlock in the study plots. Felled stems were not removed from the plots except in a few plots established in 1971 and 1972.

3.1.6 Subsequent plot measurements

Diameters (dbh) of all residual trees were remeasured during the first dormant season after treatment; tree heights were not remeasured in this first post-treatment ("initial") measurement. Following the initial measurement, complete remeasurements of diameters and heights, and re-evaluations of qualitative information were made during the dormant season at 3-year intervals.

A program of aerial photography and precise grid mapping of stems was developed to evaluate tree height growth from a sequential record of specific crown and height measurements and coordinates of all trees on study plots. Each plot was photographed from the air following Inventory Branch fixed-base air photography techniques, using colour and/or black and white film and two Hasselblad MK70 cameras mounted on a specially constructed boom (Bradatsch 1981). The procedure provided low-altitude stereo pairs of photographs for each plot.

Photography was repeated for at least two remeasurements, usually in autumn. Most problems encountered with the correspondence of trees on the photos and the grid maps were overcome. However, despite extensive field checks and computer editing of height and dbh measurements taken at ground level, heights calculated from the air photos did not compare well with corresponding ground measurements.[7] The program was discontinued in 1982 because of cost and unsuitability for evaluating short-term height growth.

As a result of the failure of the air photos to provide accurate height measurements, and because of a shift of project objective from basal area response to volume response, the criteria for selecting height sample trees changed from subjective selection of 10 of the largest trees (Section 3.1.4), to a scheme dependent on crown class and stand composition of each plot.

The current selection criteria for height sample trees are as follows:

1. in pure stands, from the predominant species: 10 dominant/co-dominant trees are selected, including the 5 largest dbh trees; 5 intermediates, including the 3 largest dbh; and 5 suppressed, including the smallest suitable dbh tree;
2. in mixed stands, for each of fir and hemlock: 8 dominant/co-dominant trees are selected, including 3 of the largest dbh; plus 4 intermediates, including the 2 largest dbh, and 3 suppressed;
3. plus, in pure or mixed stands: 5 trees of any third major commercial species are selected, 1 tree from each existing crown class and the remainder from the most frequently occurring crown class(es); for redcedar, up to 5 trees are selected, if available, and include the largest and smallest dbh tree; for other minor or scattered commercial species, one height is recorded in the crown class most frequently occupied by that species.

If the required number of sample trees in a crown class is not available, trees are not substituted from other crown classes. In subsequent sampling, previously measured healthy survivor trees are preferred.

This sampling scheme provides a valid top height measurement only for 0.05-ha plots in pure stands. An increased sampling effort to include heights of two and five more dominant/co-dominant trees of the largest dbh for each species in pure and mixed stands in 0.07- and 0.10-ha plots, respectively, is required.

3.1.7 Soils

Soil sampling was conducted by the B.C. Department of Agriculture, Soils Branch, after all plots were established. In each installation, two to three soil profiles were described using standard terminology

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7 Ibid.

(Dumanski 1978), a comprehensive description of physical characteristics of the soil was made, and litter and mineral samples were collected for chemical analysis and moisture and bulk density determination. The data are now contained in the B.C. Soil Information System (Sondheim and Suttie 1983), and have been checked through the validation procedure (Sondheim 1983).

3.1.8 Vegetation

Percent cover, dominance, and vigour of understory vegetation were initially subjectively evaluated in each plot in five 1.0-m radius subplots. The data were supplemented by casual observations outside the plots.[8] Plots with comparable flora were segregated by dissimilarity analysis, but problems were encountered in relating these groups to trends observed in the field.[9] Furthermore, the technique relied only on presence or absence of various species, regardless of indicator value and abundance, so the method was subsequently replaced by an ecosystem or biogeoclimatic approach (Annas *et al.* 1979; Pojar 1983).

Accordingly, a general inspection was conducted for representative sites in each installation rather than in each plot, and each major vegetation type per installation was described using one representative sub-plot.[10] Some apparently homogeneous stands were therefore represented by a single sampling effort. Descriptions recognized layers or strata based on height and life-form, and cover-abundance was estimated using the Domin-Krajina scale (Mueller-Dombois and Ellenberg 1974). Each installation was designated to an appropriate biogeoclimatic subzone (Klinka *et al.* 1984) according to climatic, edaphic, topographic, and floristic features, and to how geographic locations related to boundaries previously proposed (Krajina 1969; Packee 1974). Eleven ecosystem units were recognized,[11] and vegetation tables were produced by computer (Klinka 1976) showing the species in each layer together with their frequency, abundance, and vigour. Finally, based on soil sampling described earlier and summarized on edatopic grids (Krajina 1969; Klinka *et al.* 1984), the moisture and nutritional status of soils were inferred from physical and chemical properties, parent material, topographic position, and existence of indicator species.[12]

3.1.9 Weather

Weather stations were established by the Climatological Section, Resource Analysis Branch, B.C. Ministry of Environment, at or near each installation, preferably on the same landform, according to standards recommended by the World Meteorological Organization (1971). At most stations, a Stevenson screen was erected with a recording thermograph, maximum and minimum thermometers for calibration, and two storage precipitation gauges nearby. Periodic measurements of snow pack and snow density were also recorded, the latter at only a few stations. The equipment was maintained for at least 1 year at all sites, and up to 8 years at certain locations (B.C. Ministry of Environment 1980). Additionally, a Belfort weighing bucket precipitation recorder was usually set up to record daily precipitation at each installation or group of adjacent installations and was most often maintained for a minimum period of 1 month before fertilizing and a similar time thereafter. Location, dates of operation, and parameters recorded are summarized in Appendix 7 of the comprehensive establishment report[13]. In 1972, weekly records from existing long-term weather stations were used to forecast the optimal period of fertilizer application in installations 1 to 18. All measurements are stored in the Climate Data Capture System maintained by the B.C. Ministry of Environment, Air Studies Branch.

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[8] R.K. Jones. 1972. Vegetation survey, Forest Productivity Committee, B.C. Forest Service, field season 1972. B.C. Dep. Lands For. Water Resources, For. Serv., Res. Div. (Available from B.C. Min. For., Research Branch, Victoria, B.C.). Unpubl. rep.

[9] R.T. Smith. 1979. An ecological classification of installations in the Forest Productivity program. B.C. Min. For., Res. Branch, Victoria, B.C. Unpubl. rep.

[10,11,12] Ibid.

[13] Darling and Omule, 1988.

3.2 Industrial installations[14]

3.2.1 Design, establishment, and treatment

Seven installations (98 0.05-ha plots) were established from 1973 to 1975 to study growth response to operational thinning (four installations, 26 plots) or fertilization (three installations, 72 plots) in 15- to 39-year-old stands. Three installations were located in areas of natural regeneration and four in plantations. Methods of plot establishment were similar to those of standard installations.

Plots in the four thinning installations were established in 1973 in stands older than 15 years. Buffers, which were approximately 10 m wide (twice the width of standard buffers), protected plots from major topographic irregularities and accidental damage by the thinning crews (Figure 3a). Buffer trees were not measured or tallied.

Basal area was calculated for each plot (excluding buffers) in the thinning installations, and plots within an installation were ranked by basal area and paired with next-ranked plots (i.e., first- and second-ranked, third- and fourth-ranked, etc.). One of each pair was randomly chosen to receive the thinning treatment and the other was designated as an untreated control plot. All four installations were chemically spaced with MSMA (monosodium methanearsonate) to pre-determined residual densities (e.g., 746 stems per hectare in installations 73 and 76). Orange "Glowon" was used in installations 73 to 75 and clear "Silvisar" in installation 76.

The three industrial fertilization installations were established in 1974 and 1975. Plots were located in areas designated as "treatment" (aerial fertilization at a target rate of 225 kg N/ha applied in the form of prilled urea, 46% N) and "no treatment" within each installation (Figure 3b). There were no buffers around plots in the treatment areas; however, the centres of plots in the control areas were at least 30 m from the edge of the treatment areas. Buffers were established only around plots in the control area in installation 78, where, in a supplementary experiment, six untreated plots (plus buffers) were fertilized by hand at 225 kg N/ha, and six at rates actually applied from the air.

The actual fertilization rate was closely monitored. Traps were arranged along transects or regularly spaced on the plots before fertilizer distribution. Sampling frames were laid out along transects following distribution. Prills were counted and the total weight of nitrogen applied per hectare was estimated. Results are on file at the Research Branch, Victoria.

3.2.2 Measurement

Preliminary (pre-treatment) tree measurements were not taken in the industrial installations. However, initial (post-treatment) measurements were recorded on all industrial installations and were subsequently also entered into the data base as preliminary measurements (Table 3). Initial measurements on thinned plots included measurements of treated stems because some trees may have survived the chemical thinning treatment. Survivors were not subsequently removed. Subsequent remeasurements on all industrial installations were taken at 3-year intervals until the 12th year after treatment. Vegetation, soils, and climate were evaluated, and stems were mapped. Fixed-base aerial photographs were taken for height estimation at the time of the post-treatment, 3-year and 6-year measurements.

In the fertilized 15-year-old stand (installation 79), all stems 1.0 m or more in height, including commercial and non-commercial species, were measured and tagged at the time of plot establishment. Dense ingrowth of stems taller than 1.0 m developed by the time of the first remeasurement, and additional stems were tagged and recorded so that stand density increased substantially. Subsequently only trees having dbh greater than or equal to 5.0 cm were measured, as in standard plots. In addition, total height, diameter at 1/3 height, and pathological condition were recorded for Douglas-fir trees at least 1.0 m tall. Ingrowth was removed from the records but not from the plots, and plot densities were calculated from eight permanent, 2-m radius subplots.

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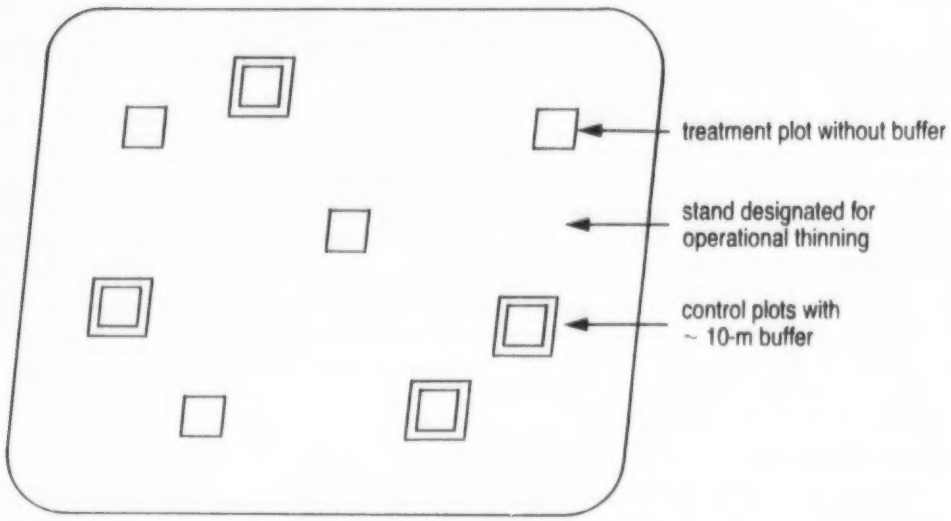
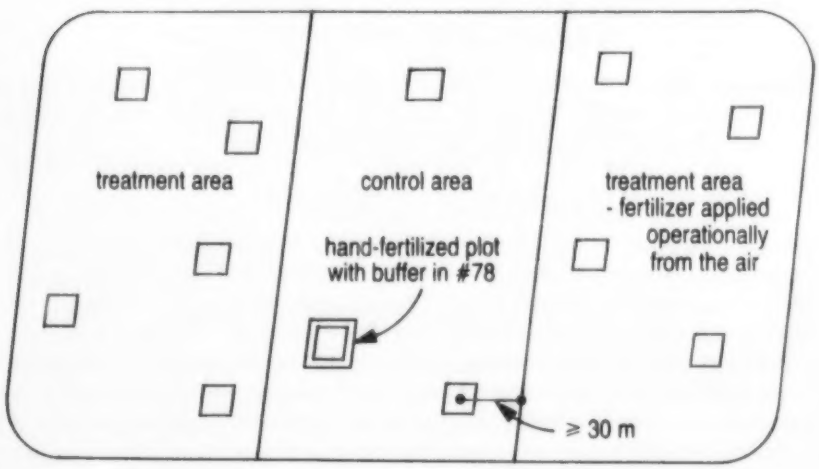
14 Information sources: memos and correspondence filed at the Research Branch, Victoria.



A. Industrial thinning trials (#73-76). All plots are within the thinning area. Only control plots have buffers to protect plots from adjacent treated areas. Equal numbers of control and treatment plots.



B. Industrial fertilizer trials (#77-79). Plots receiving the fertilizer are in a swath or block(s) designated for treatment, control plots are in adjacent untreated areas. There are no buffers, except in hand-fertilized plots in the control area in #78; centres of control plots are at least 30 m from boundary of treated area. More plots treated than retained as control plots.

FIGURE 3. Typical layout of industrial thinning and fertilizer trials.

3.3 Juvenile Installations[15]

3.3.1 Design, establishment, and treatment

Six installations (36 0.05-ha plots) were established in 1975 specifically to examine the response of stands less than 15 years old to fertilizer and thinning treatments. Five installations were naturally regenerated and one was in a plantation. Plots were established in stands that were uniform in terms of topography, soils, and stand parameters (height, density, and age). Procedures followed those outlined for standard plots.

The juvenile installations did not conform to the 3×3 factorial arrangement of the standard installations (Section 3.1.1) in that thinning was designed to reduce stand densities to 600, 1200, or 1800 stems per hectare rather than to remove a specified proportion of standing basal area. However, levels of fertilizer examined (0, 225, and 450 kg N/ha) and methods of thinning and fertilizing were the same as in standard installations. Once the appropriate thinning treatment had been chosen for an installation, the thinning and fertilizing treatments were assigned randomly to plots and applied in the dormant season.

Plots were thinned before measurement. Unlike in standard installations, fertilizing was conducted after thinning because pre-spacing densities impeded movement and prevented uniform fertilizer application. Furthermore, the amount of slash was much less in the juvenile installations, and did not hamper movement or prevent fertilizer from reaching the soil. Sometimes fertilizer was applied shortly after the initial (post-treatment) measurement.

3.3.2 Measurement

Following treatment, the total height, dbh, tree class, and pathological condition were recorded for all trees at least 5.0 cm dbh. Trees less than 5.0 cm dbh but taller than 1.0 m were measured for total height and diameter at 1/3 height, and pathological condition and tree class were recorded. Stand age was determined from the stumps of the thinnings. Soil, vegetation, and climate data were collected at each installation as in the standard installations, and stem mapping and 70 mm photography were conducted. Despite substantial ingrowth, there was no re-spacing to original stand densities, and subsequent densities were estimated from eight temporary, 2-m radius subplots.

4 ANCILLARY STUDIES

Several studies outlined in Table 5, distinct from the EP 703 study, have been conducted in or near the FPC installations to take advantage of established sites with known characteristics, treatments, and long-term growth response data. Readers are directed to the specific reports for further details.

5 DATA MANAGEMENT

The tree measurement data are incorporated into the Growth Information Data Base (GIDB) of the Inventory Branch as separate plot and tree master files (GMFP and GMFT, respectively) using the Mark IV hierarchical file structure. The GMFP consists of plot identification, measurement dates, thinning record, fertilization record, soils record, stem map coordinates, and comment cards. The GMFT contains records for each tree measured in the plots, including fixed variables that identified each tree (e.g., installation number, plot number, tree number, stem coordinates) and variables that were remeasured every 3 years (e.g., dbh, total height, pathological condition). Incoming remeasurement data are edited using two Mark IV edit routines, which ensure the data meet specifications of expected growth and changes in qualitative features since the previous measurement.

For analysis and reporting purposes, the data are transcribed from the GIDB master files into Statistical Analysis System (SAS) data sets as each remeasurement is completed and the data are edited. The large tree detail file (TDF) is sorted by installation and stored in three separate subsets for standard installations (Douglas-fir, western hemlock, and mixed-species), and one subset for industrial and juvenile installations. Plot

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15 Information sources: memos and correspondence filed at the Research Branch, Victoria, and P.R. Barker. 1975. EP 703 Responses of Douglas-fir and western hemlock to juvenile spacing and fertilizer application-working plan for the period January to December 1975. B.C. Dep. For., Res. Div. (Available from Res. Branch, Victoria, B.C.). Unpubl. ms.

TABLE 5. Description of ancillary studies

Study	Objectives	Source
Increment core sampling	To examine the effects of fertilizing and thinning Douglas-fir and western hemlock stands by comparing radial growth of trees before and after treatment from breast height samples, 9 years after treatment; to consider tree and installation parameter effects (e.g., crown class, site index) to supplement growth response data from installations without control plots.	Smith(1983);[a] Smith and Barker(1984)[b]
Site-specific prediction of Douglas-fir response to fertilization	To correlate the chemical content of foliage and soil in unfertilized areas with growth response to nitrogen fertilization in adjacent areas (fertilized only).	Ballard and Carter(1987)[c]
Net primary production, production allocation, and foliage efficiency	To establish the relationship between Douglas-fir foliage biomass and (i) individual tree variables (e.g., dbh, sapwood b.a.), (ii) an index of competition, and (iii) periodic increments of stem, foliage, and total above-ground biomass, in untreated plots. From this and the following study, to estimate the proportion of total net primary production that is allocated to above-ground growth.	Kurz (in prep.)[d]
Seasonal dynamics of fine root biomass and production	To investigate the seasonal dynamics of live and dead fine root biomass and calculate fine root production and mortality estimates in second-growth coastal Douglas-fir.	Kurz and Kimmins (1987)
Fertilizer application and sampling season effects on growth and nitrogen concentration	To determine the concentration of total N, ninhydrin-positive compounds, monosubstituted-guanidino compounds, Arginine, Proline, and soluble N in bark and roots of Douglas-fir, at 3 years post-treatment in fertilized-only plots; to examine the above concentrations monthly, at 4 years post-treatment; to determine the monthly concentration of mineralizable N in litter, humus and soil, 4 years post-treatment.	van den Driessche and Webber (1977a, 1977b)
Understory response to thinning and fertilization	To determine the magnitude of response to thinning and fertilizer treatments by deer and elk forage species in the understory.	Nyberg *et al.* (in prep.)[e]

[a] Smith, J.H.G. 1983. Summary report on increment core sampling in Forest Productivity installations. Unpubl. report prep. for B.C. Min. For., Res. Branch, Victoria, B.C.

[b] Smith, J.H.G. and P.R. Barker. 1984. Tree ring analyses quantify amount and duration of effects of fertilization and thinning on Douglas-fir. 2nd draft. Unpubl. report prep. for B.C. Min. For., Res. Branch, Victoria, B.C.

[c] Ballard, T.M. and R.E. Carter. 1987. Site specific prediction of Douglas-fir response to fertilization. Contract Res. Rep., Univ. B.C., to B.C. Min. For. Lands, Res. Branch, Victoria, B.C.

[d] Kurz, W.A. (In prep.) Net primary production, production allocation and foliage efficiency in second growth Douglas-fir stands with differing site quality. Ph.D. thesis. Univ. B.C., Vancouver, B.C.

[e] Nyberg, J.B., L. Peterson, and L.A. Stordeur. (In prep.) Understory response to thinning and fertilization. Integrated Wildl.-Intensive For. Res. Program, B.C. Min. For., Victoria, B.C.

summaries are provided for several variables including species composition, density, diameter distribution, basal area, height, volume, merchantable volume, and mortality. Fixed plot characteristics, such as soil properties, treatment codes, and preliminary site index, are stored in the SAS plot header file (PHF) which can be merged with the TDF for analysis.

Currently, the data are complete and fully edited for all installations up to the 12-year measurement. The 12-year data have not yet been transcribed from the GIDB master files. However, the data up to the 9-year measurement have been, and the standard installations are summarized to 9 years after treatment in terms of basal area.

6 LIMITATIONS OF THE STUDY

The design of EP 703 and the collection of data have created limitations to both the analysis and interpretation of the data. Most limitations are due to complications inadvertently introduced to the project because of its magnitude and its 4-year period of establishment. The limitations are not insurmountable, but they must be kept in mind.

6.1 Experimental Design

i. *Blocking*

- Situation: Plots on each installation were allocated to two blocks according to the preliminary basal area of the plot plus buffer. One of each treatment combination was applied to a plot from each block, so the two plots were potentially substantially different. Although the treatments were replicated within an installation, they were not replicated within the blocks.
- Limitation: Treatment response on two potentially different plots (with the same treatment) is compared to control growth on two potentially different plots.

ii. *Plot size variation*

- Situation: Due to difficulty in finding sufficiently stocked stands of older trees, installations were established where 0.07- and 0.10-ha plots were required to attain a minimum of 60 trees per plot.
- Limitation: Not enough of these installations were established to allow separate evaluation, and not all treatments, sites, or stand types were represented. Comparison among installations with different plot sizes adds complexity to interpretation of the results.

iii. *Changes to study design*

- Situation: The study design was amended as plot establishment progressed. Some installations were established with more or less plots than initially desired, some with no control plots, and not enough plots with higher levels of treatments (50% b.a. thinned and/or 675 or 900 kg N/ha) for good comparison.
- Limitation: The full data set cannot be used in all the analyses because some treatments are poorly represented. For example, analysis of variance (ANOVA) cannot be applied across the board as planned at project initiation.

6.2 Data Collection

i. *Changes over time*

- Situation: For the most part, particular parameters were evaluated consistently throughout plot establishment and remeasurement. However, standard field techniques and data recording have been altered over time, as indicated by the series of revisions to the inventory manual.
- Limitation: These changes add to the factors that must be considered when the results are interpreted.

ii. *Insufficient height measurements*

- Situation: The failure of air photographs to provide accurate height estimates in the early part of the project, and lack of concurrent height estimates from the ground, have left a large gap in the data, particularly because many practicing forest managers are interested in tree growth in terms of volume rather than basal area.

- Limitation: Tree volumes have been difficult to determine from the available data, and even the current scheme for sampling tree heights does not provide valid top height estimates for all plots.

iii. *Ingrowth*

- Situation: Ingrowth has not been removed from any plots, although its growth and abundance in the younger stands has been considerable.
- Limitation: Although ingrowth would not be removed from an operational stand, its presence may have a profound effect on growth, particularly in young stands where it might successfully compete for nutrients and/or sunlight. From a research point of view, then, ingrowth that is not removed confounds the effects of the treatment.

iv. *No preliminary measurements*

- Situation: No preliminary measurements were taken in the industrial and juvenile thinning installations because basal area calculations were not required to accommodate the study design, and stocking levels were very high.
- Limitation: The pre-treatment densities have an influence on growth after treatment, particularly in conjunction with site quality. Although growth response from the post-treatment condition is valuable, the practicing forest manager is likely to be more interested in knowing how a stand of a particular pre-treatment density will respond to a variety of thinning treatments.

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APPENDIX 1. Establishment dates, measurement dates, and stand characteristics of standard installations (Nos. 1–72), industrial installations (Nos. 73–79), and installations established in stands less than 15 years old (Nos. 80–85)

Installation No.	No. of plots	Estab. date[1]	Stand origin[2] Stand type[3]	Prelim.[4] sp. comp. (% b.a.)			Initial[5] sp. comp. (% b.a.)			Plot size (ha)	Thin. treatment (% b.a. removed)	Fert. treatment (kg N/ha applied)	Measurement date[6]						Mean site index[7]	Prelim.[8]		Initial[8]		Mean total age (y)[9]	Mean total height (m)[9]	Quadratic mean dbh (cm)[9]
				Fd	Hw	Other	Fd	Hw	Other				Prelim.	Initial	3-year	6-year	9-year	12-year		stems/ha	m²/ha	stems/ha	m²/ha			
1	18	720514	CF	89.5	5.9	4.6	90.8	4.8	4.4	.05	0,20,35	0,225,450	72	72	75	78	81	84	29	1696	36.14	1119	29.50	36	23	16.4
2	18	720714	NFH	77.6	21.6	0.7	80.1	19.4	0.5	.05	0,20,35	0,225,450	72	72	75	78	81	84	18	2442	19.06	1873	15.96	30	12	9.9
3	18	720609	NF	88.7	5.8	5.5	90.7	5.0	4.3	.05	0,20,35	0,225,450	72	72	75	78	81	84	27	1393	42.09	974	34.89	43	24	20.0
4	18	720611	CF	94.2	3.6	2.2	95.2	3.3	1.5	.05	0,20,35	0,225,450	72	72	75	78	81	84	23	2510	31.12	1844	26.03	30	15	12.7
5	18	720610	PF(H)	82.3	14.7	3.0	83.7	13.5	2.8	.05	0,20,35	0,225,450	72	72	75	78	81	84	26	3484	40.53	2685	33.89	27	15	12.4
6	8	720822	NF	95.4	1.7	2.9	96.6	1.5	1.9	.10	20,35	225,450	72	72	75	78	81	84	25	1471	34.11	942	24.72	39	20	17.2
7	10	720815	NF	95.8	0	4.2	96.7	0	3.3	.05	0,20,35	0,225,450	72	72	75	78	81	84	21	2384	36.41	1938	32.29	39	17	14.1
8	14	72	NFC	74.1	4.6	21.3	78.0	3.2	18.8	.05	0,20,35	0,225,450	72	72	75	78	81	84	25	2344	44.07	1440	34.50	39	21	15.6
9	8	720713	PFH	73.6	23.8	2.6	81.0	17.4	1.6	.05	20,35	225,450	72	72	75	78	81	84	28	3812	43.96	2305	32.19	27	17	12.2
10	10	720720	PF(H)	84.0	10.3	5.7	85.3	9.6	5.0	.05	0,20,35	0,225,450	72	72	75	78	81	84	24	3534	40.96	3012	36.92	29	16	12.2
11	8	720723	PF	94.5	2.6	2.9	94.5	2.6	2.9	.05	0	0,225,450,675	72	72	75	78	81	84	27	3282	41.68	3282	42.11	25	15	12.8
12	8	720723	PF	98.1	0.9	1.0	98.1	0.9	1.0	.05	0	0,225,450,675	72	72	75	78	81	84	24	3460	31.99	3460	32.60	23	12	10.9
13	10	720730	PF	96.1	1.4	2.5	96.8	1.2	2.0	.05	0,20,35	0,225,450	72	72	75	78	81	84	21	3254	31.00	2638	28.10	28	13	
14	10	720813	PF	92.0	6.5	1.5	93.1	5.8	1.1	.05	0,20,35	0,225,450	72	72	75	78	81	84	26	2756	28.32	2278	25.50	22	13	11.5
15	8	7208	PF	98.2	0	1.8	99.8	0	0.2	.05	20,35	225,450	72	72	75	78	81	84	35	1657	43.83	885	31.15	26	20	18.4
16	10	720801	PF	94.2	0.5	5.4	94.5	0.4	5.0	.05	0,20,35	0,225,450	72	72	75	78	81	84	30	2678	24.10	2332	22.25	19	12	10.6
17	8	720807	PF	97.7	1.0	1.3	97.9	0.5	1.6	.05	20,35	225,450	72	72	75	78	81	84	16	1917	23.81	1125	17.69	33	12	12.6
18	8	720811	NF	95.8	2.5	1.7	95.8	2.4	1.7	.05	0	0,225,450,675	72	72	75	78	81	84	34	830	49.74	830	50.23	45	31	27.8
19	6	730614	NF	96.8	3.1	0.1	96.3	1.6	0.1	.07	0,20,35	0	73	73	76	79	82	85	31	1042	45.82	788	37.97	42	27	23.7
20	6	73	NFH	77.4	21.6	1.1	77.5	21.5	1.1	.05	0	0,225,450	73	73	76	79	82	85	24	1780	51.62	1783	52.48	43	22	19.2
21	8	730812	NF(H)	85.1	11.8	3.1	88.2	9.4	2.4	.05	20,35	225,450	73	73	76	79	82	85	23	1982	50.76	1210	36.81	42	20	18.2
22	14	73	NFH	66.2	32.3	1.6	71.4	27.3	1.3	.05	0,20,35	0,225,450	73	73	76	79	82	85	26	1640	58.56	1130	45.00	42	24	21.6
23	12	730522	PF	99.7	0	0.3	100.	0	0	.05	20,35	225,450,675	73	73	76	79	82	85	26	2578	23.15	1590	17.69	20	11	10.7
24	8	73	NHF	29.0	66.7	4.2	35.3	61.1	3.6	.05	20,35	225,450	73	73	76	79	82	85	19	4987	42.77	3007	31.14	30	12	10.5
25	14	730819	NF	92.4	5.1	2.5	92.7	4.9	2.4	.07	0,20,35	0,225,450	73	73	76	79	82	85	30	1089	73.17	843	62.26	68	35	29.5
26	8	730813	NF	92.7	6.1	1.3	95.5	4.3	0.2	.05	20,35	225,450	73	73	76	79	82	85	20	3265	47.56	1980	34.74	47	19	13.8
27	8	730428	PF	96.5	0.4	3.1	98.1	0.3	1.5	.05	20,35	225,450	73	73	76	79	82	85	22	3455	27.54	2175	21.24	25	13	10.1
28	26	73	NH	0	99.8	0.2	0	99.8	0.2	.05	0,20,35	0,225,450,675,900	73	73	76	79	82	85	28	4150	60.50	3187	50.16	34	20	13.7
29	10	73	NH	0	98.1	1.9	0	98.1	1.9	.05	0	0,225,450,675,900	73	73	76	79	82	85	28	3770	62.22	3770	62.00	33	20	14.7
30	32	73	NH	0	94.9	5.1	0	95.2	4.8	.05	0,20,35,50	0,225,450,675	73	73	76	79	82	85	25	3636	57.87	2239	43.50	32	17	14.4
31	6	73	NH	0	96.7	3.3	0	97.1	2.9	.05	0,20,35	0	73	73	76	79	82	85	25	5603	63.96	4253	51.44	38	19	12.3
32	6	73	NH(C)	1.4	85.4	13.1	1.5	88.1	10.4	.05	0,20,35	0	73	73	76	79	82	85	28	1943	60.17	1426	49.83	45	26	19.9
33	22	73	NH	0.7	95.5	3.8	0.1	96.4	3.4	.05	0,20,35,50	0,225,450,675	73	73	76	79	82	85	29	1677	69.99	1215	56.72	44	26	23.5
34	6	73	NH	1.1	96.6	2.3	1.1	96.6	2.3	.05	0	0,225,450	73	73	76	79	82	85	26	1930	61.73	1940	61.98	45	24	20.2
35	22	73	NH	0.8	95.5	3.7	0.4	95.9	3.7	.05	0,20,35,50	0,225,450,675	73	73	76	79	82	85	26	2185	66.86	1627	54.20	45	24	19.9

APPENDIX 1. *Continued*

Installation No.	No. of plots	Estab. date[1]	Stand origin[2] Stand type[3]	Prelim.[4] sp. comp. (% b.a.)			Initial[5] sp. comp. (% b.a.)			Plot size (ha)	Thin. treatment (% b.a. removed)	Fert. treatment (kg N/ha applied)	Measurement date[6]						Mean site index[7]	Prelim.[8]		Initial[8]		Mean total age (y)[9]	Mean total height (m)[9]	Quadratic mean dbh (cm)[9]
				Fd	Hw	Other	Fd	Hw	Other				Prelim.	Initial	3-year	6-year	9-year	12-year		stems/ha	m2/ha	stems/ha	m2/ha			
36	16	73	NH	1.0	98.5	0.5	1.0	99.0	0	.05	20,35	225,450,675,900	73	73	76	79	82	85	29	2003	66.61	1192	47.06	46	27	20.9
37	12	73	NHF	23.2	73.2	3.7	26.1	70.9	3.0	.05	20,35	225,450,675	73	73	76	79	82	85	30	1211	64.82	750	46.85	50	29	26.2
38	22	74	NFH	58.5	41.1	0.4	61.2	38.6	0.2	.10	0,20,35,50	0,225,450,675	74	74	77	80	83	86	32	822	80.00	820	80.23	60	36	35.4
39	12	73	NH	3.7	96.0	0.3	4.1	95.9	0.1	.05	20,35	225,450,675	73	73	76	79	82	85	30	1536	63.34	951	46.25	53	31	23.2
40	30	74	NHF(C)	37.6	51.9	10.5	45.5	47.7	6.8	.07	0,20,35,50	0,225,450,675	74	74	77	80	83	86	31	1238	80.98	1242	81.62	53	32	29.0
41	4	740801	NF	93.1	1.4	5.5	93.1	1.4	5.5	.05	0	0,225	74	74	77	80	83	86	23	2310	28.61	2310	28.87	30	15	12.6
42	4	74	NFH(C)	64.7	20.0	15.3	64.9	19.9	15.2	.05	0	0,450	74	74	77	80	83	86	28	1890	39.73	1890	40.93	33	20	16.4
43	10	74	NF(H)(C)	70.8	19.2	10.0	74.5	17.2	8.2	.05	0,20,35	0,225,450	74	74	77	80	83	86	26	2570	44.19	2568	44.49	35	20	14.8
44	14	74	NFH(C)	67.4	20.2	12.4	72.9	18.1	9.0	.05	0,20,35	0,225,450	74	74	77	80	83	86	28	2405	39.53	2405	40.23	33	21	14.7
45	16	74	NFH	52.3	45.2	2.5	59.4	40.5	0	.05	35,50	225,450,675,900	74	74	77	80	83	86	29	1675	57.10	1415	52.83	53	31	21.1
46	14	74	NF	88.9	6.1	5.0	92.6	5.1	2.3	.07	0,20,35	0,225,450	74	74	77	80	83	86	29	1272	55.17	1196	53.57	53	30	23.9
47	18	740527	NF	99.0	0.2	0.8	99.3	0.1	0.6	.07	0,20,35	0,225,450	74	74	77	80	83	86	26	1400	57.22	1400	57.99	61	30	23.0
48	6	740722	NF	89.0	1.0	9.9	89.1	1.0	9.9	.05	0	0,225,450	74	74	77	80	83	86	19	2796	33.53	2796	33.71	37	16	12.4
49	4	74	NF(H)(C)	67.1	17.8	15.1	72.3	17.1	10.6	.05	0,35	0	74	74	77	80	83	86	30	3045	43.23	3045	44.05	33	21	13.5
50	16	740520	PF	93.7	4.0	2.2	96.9	2.8	0.3	.05	20,35	225,450,675,900	74	74	77	80	83	86	23	2717	27.67	2720	28.59	30	15	11.4
51	6	74	NFH	53.8	38.6	7.7	63.2	30.3	6.5	.05	0,35,50	0	74	74	77	80	83	86	32	3796	54.15	2193	39.43	33	23	13.5
52	6	740801	PF	88.2	9.7	2.1	92.1	6.8	1.1	.05	0,20,35	0	74	74	77	80	83	86	27	2366	35.13	2366	35.04	24	14	13.8
53	4	740809	PF	97.8	1.2	1.0	97.9	0.9	1.2	.05	0,50	0	74	74	77	80	83	86	28	2615	39.98	2615	40.02	23	15	14.2
54	4	74	PFH	70.9	24.2	4.9	75.2	20.8	4.0	.05	0,50	0	74	74	77	80	83	86	23	4310	35.84	2865	26.78	26	14	10.3
55	4	740822	PF	94.3	1.8	3.9	94.0	1.8	4.2	.05	0	0,675	74	74	77	80	83	86	27	1810	34.66	1810	34.93	28	17	15.6
56	32	74	NH	0	91.9	8.1	0	93.0	7.0	.07	0,20,35,50	0,225,450,675	74	74	77	80	83	86	33	964	79.06	965	79.25	64	39	32.5
57	4	74	NH	0	87.6	12.4	0	87.6	12.4	.10	0	0,900	74	74	77	80	83	86	33	787	82.36	787	82.43	63	39	36.6
58	12	74	NH	0	95.8	4.2	0	95.6	4.4	.07	35,50	450,675,900	74	74	77	80	83	10	35	851	79.83	852	79.68	63	41	34.6
59	8	74	NH	0	95.4	4.6	0	95.4	4.6	.05	20,35	225,450	74	74	77	80	83	86	32	1422	84.40	1427	84.37	63	37	27.9
60	8	740818	NF(H)	85.8	13.9	0.2	85.8	13.9	0.2	.07	0	0,225,450,675	74	74	77	80	83	86	31	1283	58.28	1285	58.44	72	37	24.5
61	6	741003	PF	96.0	0.2	3.8	95.9	0.2	3.9	.05	0	0,675,900	74	74	77	80	83	86	30	1850	40.60	1850	40.60	31	20	16.8
62	4	741022	NF	96.3	1.1	2.7	96.3	1.1	2.7	.05	0	0,675	74	74	77	80	83	86	27	1515	42.38	1510	42.35	44	24	19.0
63	4	74	NFH	59.9	38.6	1.5	59.9	38.6	1.5	.05	0	0,225	74	74	77	80	83	86	16	3320	52.31	3320	52.34	80	20	14.2
64	10	75	NH	0	96.8	3.2	0	96.7	3.3	.05	0,35,50	0,225,450	75	75	78	81	84	87	25	6378	46.62	6380	47.00	31	16	9.7
65	6	750507	NF(H)	86.1	12.3	1.6	92.3	7.1	0.6	.05	0,35,50	0	75	75	78	81	84	87	27	3166	40.32	1940	29.91	29	17	12.8
66	4	75	NH(F)	10.9	88.0	1.1	11.7	87.5	0.7	.05	0,35	0	75	75	78	81	84	87	30	1510	69.84	1510	70.08	47	29	24.5
67	4	75	NH	1.9	94.5	3.5	2.4	95.0	2.7	.05	0,35	0	75	75	78	81	84	87	27	2090	64.57	2095	65.84	43	23	20.2
68	4	750625	NF(H)	83.6	12.0	4.4	83.6	12.1	4.3	.07	0	0,225	75	75	78	81	84	87	26	1935	43.49	1935	44.16	41	23	17.1
69	10	75	NFH	72.4	25.5	2.1	72.4	25.5	2.1	.07	0	0,225,450,675,900	75	75	78	81	84	87	29	1589	47.54	1592	48.22	41	25	20.0

APPENDIX 1. *Concluded*

Installation No.	No. of plots	Estab. date[1]	Stand origin[2] Stand type[3]	Prelim.[4] sp. comp. (% b.a.)			Initial[5] sp. comp. (% b.a.)			Plot size (ha)	Thin. treatment (% b.a. removed)	Fert. treatment (kg N/ha applied)	Measurement date[6]						Mean site index[7]	Prelim.[8]		Initial[8]		Mean total age (y)[9]	Mean total height (m)[9]	Quadratic mean dbh (cm)[9]
				Fd	Hw	Other	Fd	Hw	Other				Prelim.	Initial	3-year	6-year	9-year	12-year		stems/ha	m²/ha	stems/ha	m²/ha			
70	8	750824	PF(H)	85.9	13.6	0.6	89.9	9.9	0.3	.05	0,20,35,50	0	75	75	78	81	84	87	30	1947	22.01	1955	22.42	16	10	12.2
71	18	710923	PF	99.2	0.3	0.5	99.3	0.3	0.5	.05	0,20,35	0,225,450	71	71	74	77	80	83	27	2432	28.90	1875	22.35	28	17	12.4
72	18	710618	NF	93.1	2.1	4.8	93.1	2.1	4.7	.05	0,20,35	0,225,450	71	71	74	77	80	83	38	717	52.40	521	41.82	53	40	30.5
73	10	73	PFH(C)	73.8	16.0	10.2	76.3	14.3	9.4	.05	0,746[11]	0	73	73	76	79	82	85	28	2874	53.10	1858	39.04	29	18	15.4
74	4	73	NHF	26.4	68.5	5.2	29.9	64.6	5.6	.05	0,746	0	73	73	76	79	82	85	27	2635	42.52	1945	36.25	26	15	14.3
75	6	73	NHF	27.7	70.5	1.8	32.6	66.4	1.0	.05	0,746	0	73	73	76	79	82	85	23	4526	52.59	2866	41.59	31	16	12.2
76	6	73	PHF	36.4	59.6	4.0	40.3	55.8	3.9	.05	0,746	0	73	73	76	79	82	85	28	4910	57.77	3633	46.41	28	16	12.4
77	18	74	NF	92.7	5.2	2.1	92.7	5.2	2.1	.05	0	0,225[12]	74	74	77	80	83	86	25	1726	32.08	1726	32.08	39	21	16.7
78	43	75	PF	99.8	0.1	0.2	99.8	0.1	0.2	.05	0	0,225	75	75	78	81	84	87	23	1458	23.89	1460	24.07	31	15	14.6
79	11	75	PF	99.1	0.9	0	98.9	1.1	0	.05	0	0,225	75	75	78	81	84	87	21					15	6	
80	6	75	NH		-?-		0	93.8	6.2	.05	1800,1200,600[13]	0		75	78	81	84	87						13	5	
81	4	75	NF(H)	50.1	38.3	10.8[14]	89.6	10.0	0.3	.05	1200	0,225		75	78	81	84	87		1601		N/A	—	13	5	N/A
82	8	75	NF	31.2	64.8	3.7	100.	0	0	.05	1200,600	0,450		75	78	81	84	87		277600				12	3	
83	8	75	NF	66.0	28.3	5.7	100.	0	0	.05	1200,600	0,225		75	78	81	84	87		184960				12	4	
84	6	75	NF	88.4	11.5	0.1	98.7	1.3	0	.05	1800,1200,600	0		75	78	81	84	87		230320				16	6	
85	4	75	PF(H)	5.8	93.0	1.2	85.5	14.5	0	.05	1200	0,225		75	78	81	84	87		13120				12	7	

1 Also year of thinning and/or fertilizer treatments applied in dormant season.
2 Stand origin: P-plantation; N-natural regeneration; C-combination.
3 Stand type: based on species composition by percent basal area at time of establishment (except, post-treatment in #80–85).
F: pure fir; 80% fir; 10% any other species
F(H): pure fir with minor hemlock; 80% fir, 10–20% hemlock
FH [or FC] = fir-dominated with major hemlock [or other]; 50–80% fir 20% hemlock [or other]
FH(C): fir-dominated, with major hemlock and minor other
F(H)(C): fir-dominated, with minor hemlock and minor other
H: pure hemlock
H(F) [or H(C)]: pure hemlock with minor fir [or other]
HF: hemlock-dominated with major fir
HF(C): hemlock-dominated with major fir and minor other
4 Preliminary: pre-treatment.
5 Initial: post-treatment.
6 Preliminary during growing season, others in dormant season.
7 Height (m) at 50 years total age calculated at establishment.
8 Density and basal area calculated from all live trees at least 5.0 cm dbh.
9 Age and height at time of establishment — calculated from a selection of dominant and co-dominant trees of the major species. Dbh at establishment — only stems at least 5.0 cm dbh.
10 Seven plots of #58 lost of original 12 due to windthrow and road construction following 6-year (1980) remeasurement; four more lost following 9-year remeasurement; terminated following 12-year remeasurement.
11 In #73–76, plots were spaced to 746 stems/ha (3.7 × 3.7 m spacing), rather than removing a percentage of standing basal area.
12 In #77–79, the target fertilization rate was 225 kg N/ha by aerial distribution; true application rate varied.
13 In #80–85, plots were thinned to 1800, 1200, and 600 stems/ha, rather than removing a percentage of standing basal area.
14 Species composition in #80–85 by stems/ha rather than by % basal area, from five 2-m radius subplots per plot, plus four per buffer. Because of thinning preferences (leave trees, stem density, regular spacing, canopy opening, etc.) the resultant stand type was substantially different than before thinning. Data not available for #80.